4A Typical Control Rod Patterns and Associated Power Distribution for ABWR

4A.1 Introduction

This appendix contains a typical simulation of an equilibrium cycle. The control rod patterns used are just one example of a set of control rod patterns which could be used to provide the radial and axial power shaping needed to meet the Technical Specifications.

[*The basic control rod strategy for this case is provided in Table 4A-1.*

4A.2 Core Loading and Power Distribution Strategy

A low-leakage core loading pattern is established for the cycle, which is simulated in depletion steps with control rod sequence swaps being done at certain steps. Multiple core simulations are carried out, repeating the same loading pattern for several cycles, until equilibrium is established with respect to the hot reference level. For each depletion step, the thermal and shutdown margins are evaluated against the limits, and the control rod pattern is fine-tuned to optimize the power distribution, yet maintaining adequate margins. Also the core loading pattern is fine-tuned in repeated core simulations (over multiple cores, until the equilibrium is re-established) until the overall power distribution, neutron economy and thermal and shutdown margins are optimized. The core simulations are evaluated using the codes described in Reference 4A-1.

4A.3 Results of Core Simulation Studies

Table 4A-2 summarizes the figures that present overviews and/or detailed information from the core simulation. The detailed data presented demonstrates that this design can be operated throughout this cycle with adequate margins to allow for operating flexibility. The variation of the minimum critical power ratio (MCPR) with cycle exposure is shown in Figure 4A-6, and the variation of the maximum linear heat generation rate (MLHGR) with cycle exposure is shown in Figure 4A-7. Adequate margins are indicated with respect to the design limits.]*

4A.4 References

4A-1 "The Advanced PHOENIX and POLCA Codes for Nuclear Design of Boiling Water Reactors", (CENPD-390-P-A, December 2000).

4A-2 "Supplemental Information for the Toshiba ABWR DCD Renewal Amendment", (WCAP -17290-P, Rev. 0).

* See Section 4.2.

Table 4A-1 Basic Control Strategy for Typical ABWR

The basic control rod strategy for this case, a 24-month equilibrium cycle, is to use deeply inserted rods as far as possible and to avoid shallow rods in order to compensate for the excess reactivity throughout the cycle. For this case, no specific control rod module cells are required, but four sequences are used with rod pattern exchanges (swaps) at certain regular depletion steps. Axially zoned fuel flattens the core axial power distribution, minimizing the need for shallow control rods. The core is operated at 90% rated core flow from the beginning of the cycle until the core is critical with all control rods withdrawn. Then the core flow is gradually increased to 111% rated core flow, maintaining criticality while extending the cycle burnup.

Table 4A-2 Core Simulation Results and Related Figures Numbers

Content	Figure Numbers
Equilibrium Cycle Simulation Summary	4A-1
Burnup Distribution at BOC	4A-2a
Burnup Distribution at EOC	4A-2b
Axial Burnup Distribution at BOC and EOC	4A-3a
Axial Power Distribution at BOC, MOC, and EOFP	4A-3b
Control Rod Sequence	4A-4a through 4A-4d
Hot Excess Reactivity as a Function of Cycle Exposure	4A-5
Minimum Critical Power Ratio as a Function of Cycle Exposure	4A-6
Maximum Linear Heat Generation Rate as a Function of Cycle Exposure	4A-7

Figure 4A-1 Equilibrium Cycle Simulation Summary [Information not included in DCD (Refer to Reference 4A-2)]

Figure 4A-1a Not Used

Figure 4A-1b Not Used

Figure 4A-1c Not Used

Figure 4A-1d Not Used

Figure 4A-2a Burnup Distribution (MWd/kg) at BOC, [Information not included DCD (Refer to Reference 4A-2)]

Figure 4A-2b Burnup Distribution (MWd/kg) at EOC, [Information not included in DCD (Refer to Reference 4A-2)]

Figure 4A-2c Not Used

Figure 4A-2d Not Used

Figure 4A-2e Not Used

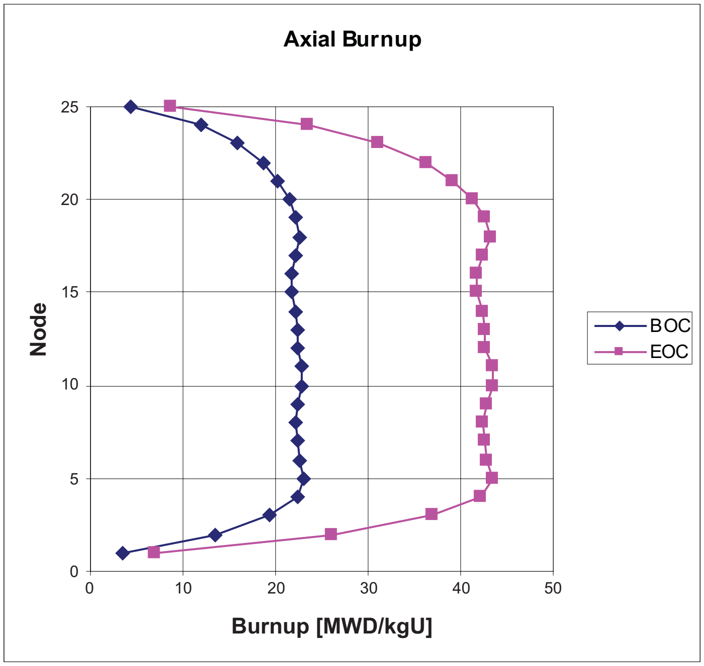

Figure 4A-3a Axial Burnup Distribution at BOC and EOC

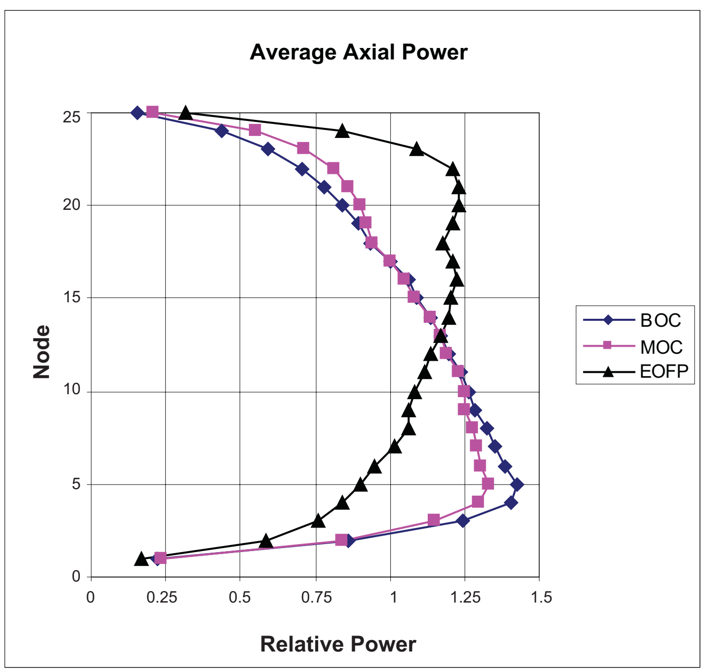

Figure 4A-3b Axial Power Distribution at BOC, MOC and EOFP

Figure 4A-3c Not Used

Figure 4A-3d Not Used

Figure 4A-3e Not Used

Figure 4A-4a Control Rod Sequence [Information not included DCD (Refer to Reference 4A-2)]

Figure 4A-4b Control Rod Sequence (continued) [Information not included in DCD (Refer to Reference 4A-2)]

Figure 4A-4c Control Rod Sequence (continued) [Information not included in DCD (Refer to Reference 4A-2)]

Figure 4A-4d Control Rod Sequence (continued) [Information not included in DCD (Refer to Reference 4A-2)]

Figure 4A-4e Not Used

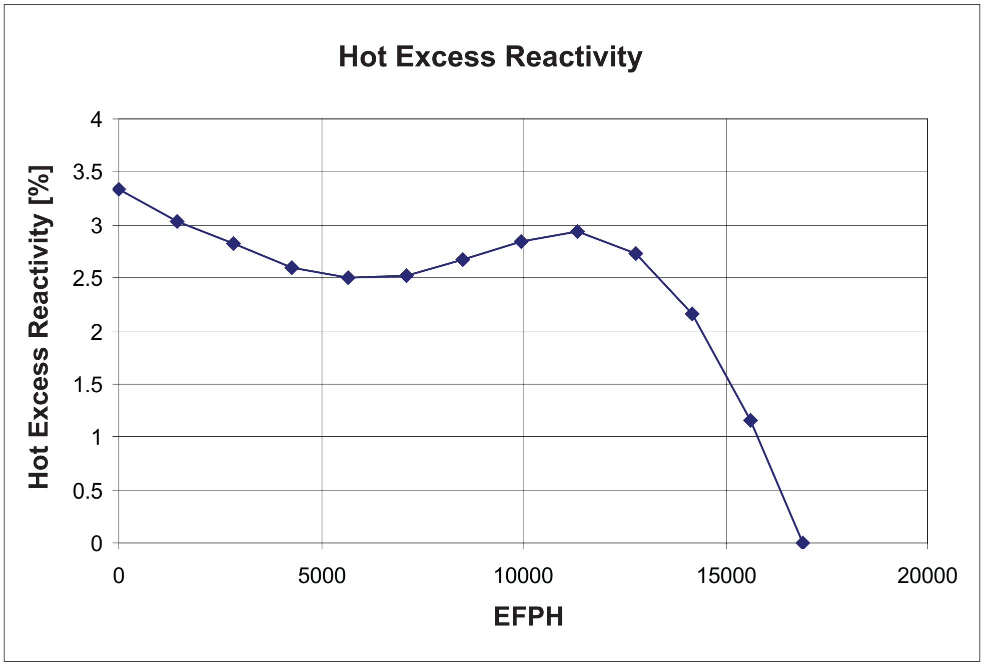

Figure 4A-5 Hot Excess Reactivity as a Function of Cycle Exposure (EFPH)

Figure 4A-5a Not Used

Figure 4A-5b Not Used

Figure 4A-5c Not Used

Figure 4A-5d Not Used

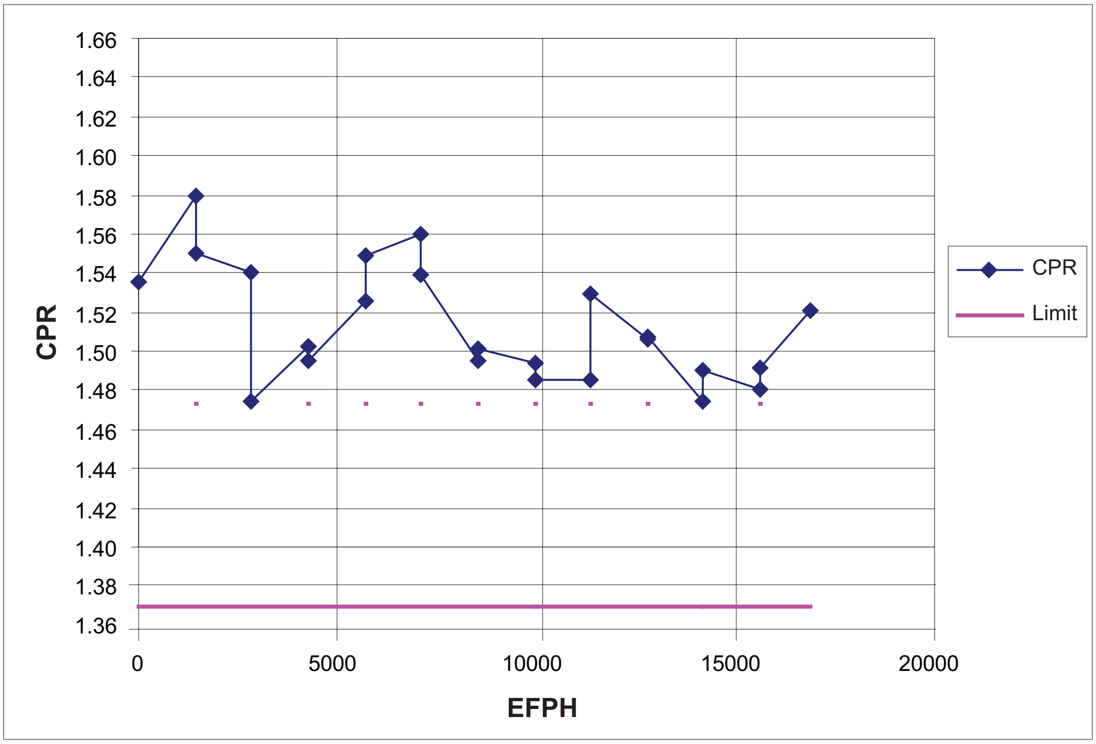

Figure 4A-6 Minimum Critical Power Ratio (CPR) as a Function of Cycle Exposure (EFPH)

Figure 4A-6a Not Used

Figure 4A-6b Not Used

Figure 4A-6c Not Used

Figure 4A-6d Not Used

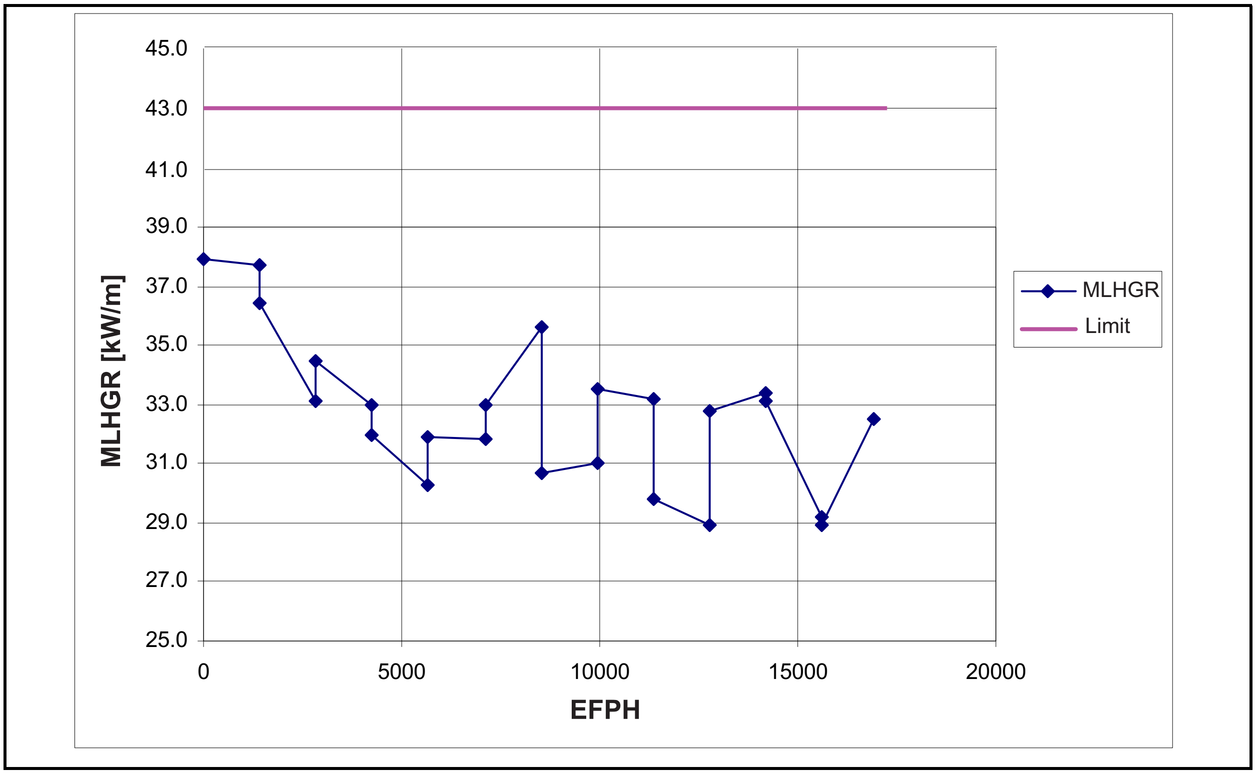

Figure 4A-7 Maximum Linear Heat Generation Rate (MLHGR) as a Function of Cycle Exposure (EFPH)

Figure 4A-7a Not Used

Figure 4A-7b Not Used

Figure 4A-7c Not Used

Figure 4A-7d Not Used

Figure 4A-8a Not Used

Figure 4A-8b Not Used

Figure 4A-8c Not Used

Figure 4A-8d Not Used

Figure 4A-8e Not Used

Figure 4A-9a Not Used

Figure 4A-9b Not Used

Figure 4A-9c Not Used

Figure 4A-9d Not Used

Figure 4A-9e Not Used

Figure 4A-10a Not Used

Figure 4A-10b Not Used

Figure 4A-10c Not Used

Figure 4A-10d Not Used

Figure 4A-10e Not Used

Figure 4A-11a Not Used

Figure 4A-11b Not Used

Figure 4A-11c Not Used

Figure 4A-11d Not Used

Figure 4A-11e Not Used

Figure 4A-12a Not Used

Figure 4A-12b Not Used

Figure 4A-12c Not Used

Figure 4A-12d Not Used

Figure 4A-12e Not Used

Figure 4A-13a Not Used

Figure 4A-13b Not Used

Figure 4A-13c Not Used

Figure 4A-13d Not Used

Figure 4A-13e Not Used

Figure 4A-14 Not Used